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GLACIATION IN THE BIGHORN MOUNTAINS.[1]

IN Vol. IX of this JOURNAL a brief outline of the results of the work done on the glacial formations of the western mountains in 1901 was given. These studies were continued during the past summer. One of the parties, under the immediate charge of the junior author of this note, spent several weeks in the Bighorn mountains of Wyoming. He was assisted by Messrs. W. H. Emmons and F. W. DeWolf, while the senior writer was with the party for about a week at the beginning of the work.

In 1900 Mr. Matthes[2] gave a discriminating description of the cirques and other topographic features in the Bighorn mountains, due to glacial erosion. In the same year Professor W. C. Knight made mention of the former existence of glaciers in the same range.[3] When the party went into the field in 1902, Professor Knight furnished it with some general notes on the geology of the range, and in these notes there was a much fuller statement of the general facts concerning the distribution of glacial drift in these mountains than had hitherto been published by him. These data had been gathered by Professor Knight in the prosecution of his other work.

So far as known to the writers, no detailed study of the drift of these mountains had been attempted previous to their work in 1902, and up to that time the existence of more than one series of glacial formations had not been recognized. The studies of last summer revealed the existence of two series of glacial formations, separated from each other by a relatively long interval of time. A third series of deposits was found, much older than the older of the preceding, which may prove to be of glacial origin, though the evidence now in hand on this point is not regarded as conclusive.

[1] Published by permission of the director of the U. S. Geological Survey.

[2] *Twenty-first Annual Report U. S. Geol. Surv.*, Part II, pp. 173–90.

[3] *A Preliminary Report on the Artesian Basins of Wyoming.* Bull. 45, Wyoming Experiment Station, p. 174.

Existing glaciers.—Five small glaciers, all less than 1¼ miles in length, still exist in the mountains in the vicinity of Cloud peak at elevations exceeding 11,200 feet. In view of the fact that the annual snowfall is not great, while the altitude of the range is moderate, the highest point having an altitude of 13,165 feet, the persistence of these glaciers is probably due primarily to the exceptionally deep and narrow cirques in which they are situated, and by whose precipitous walls they are partially sheltered from the sun, and from desiccating winds.

Drift of the last glacial epoch.—The work of the latest series of glaciers in the Bighorns was similar to that which has been described from other ranges in the western mountains. They affected a tract about 45 miles long and 20 miles wide, extending from the head of the South Fork of Tongue river on the north to the head of the southernmost tributary of Clear creek on the south. The glaciers were, for the most part, of the simple valley type, though in many cases the glaciers of several tributary valleys united into one, in the main valley below. Nowhere was there a well-developed ice-cap, though the expanse of ice in some of the valleys was considerable. In length the glaciers varied from 1 to 14 miles, and the largest of them crossed the plateau above which the sharper part of the range rises, but in no case did they reach the plains beyond.

The altitude necessary for the development of glaciers was rather more than 10,000 feet in most of the valleys, but one glacier (South Fork of Tongue river) was developed at an elevation of little more than 9,000 feet. In this case there was a favorable catchment basin on a north slope, protected against warm, drying winds.

About forty-five well-developed cirques are shown on the Cloud peak quadrangle. All of them were occupied by glaciers of the last glacial epoch, and all but two of the late Pleistocene glaciers had their sources in cirques, and were concerned in their formation. The exceptions were the feeble tongues of ice at Dome lake, and at the head of the South Fork of Tongue river.

Not counting the small feeders of larger glaciers, the deposits

of twelve distinct glaciers or systems of glaciers were studied. They occur in the following valleys:

	Length.
1. Four tributaries of the South Fork of Clear creek, the several glaciers uniting into one below	about 6 miles
2. Little cliff-glacier, south of the South Fork of Clear creek,	" 1 mile
3. Middle Fork of Clear creek	" 1 "
4. South branch of the North Fork of Clear creek	" 4 miles
5. North Fork of Clear creek	" 10 "
6. South Fork of South Piney creek	" 8 "
7. North Fork of South Piney creek	" 12 "
8. East Fork of Big Goose creek	" 9 "
9. West Fork of Big Goose creek	" 8 "
10. South Fork of Tongue river	" 6 "
11. Willett creek	" 3 "
12. Shell creek	" 14 "

In addition to the above, glacial formations are known in the following valleys, though they were not studied in detail during the past summer:

13. Trapper creek.
14. North Fork of Medicine Lodge creek.
15. South Fork of Medicine Lodge creek.
16. North Fork of Paintrock creek.
17. Middle Fork of Paintrock creek.
18. Buckskin Ed creek.
19. Tensleep creek.

The glaciers of the last glacial epoch made deposits consistent with their various sizes and activities. In general, the lateral and terminal moraines are more conspicuous than the ground moraines, while the amount of drift is slight near the sources of the glaciers, and great below. The lateral moraines are long, sharp ridges, paralleling the sides of the valleys, and have rather even crest-lines, 500–700 feet above the streams. Their proximal ends usually lie against the rocky sides of the glacial canyons at an elevation of about 10,000 feet, while their distal ends merge into the stout terminal moraines. The outer fronts of the terminal moraines frequently rise somewhat abruptly 400 to 500 feet above the valley below, and their surfaces often possess in a notable degree the hummocky topography characteristic of these formations. Valley trains are present below the terminal moraines, but they are not usually very conspicuous.

One of the most striking features of the youngest series of glacial deposits is the extremely fresh appearance of the drift, and the trivial extent of the inroads which weathering and erosion have made on it and on the rock of the canyon walls and *roches moutonnées* within the area where it occurs. The till often shows scarcely a trace of surface oxidation. The numerous lakes in the valleys occupied by the glaciers of the last ice epoch, many of them confined by drift dams in valleys which have steep gradients and copious drainage, are clear indications of the

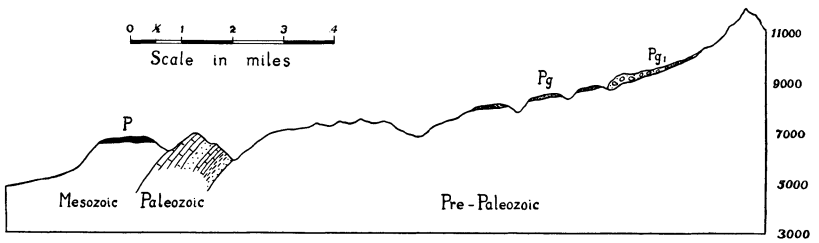


FIG. 1.—Section from near Fort McKinney to the head of the South Fork of Clear creek, showing the distribution of the Pleistocene formations: *P*, Bald mountain beds; *Pg*, drift of the next to the last glacial epoch; Pg_1, drift of the last glacial epoch.

recency of glaciation. The amount of postglacial stream erosion has been slight in most cases. It is at a maximum where the streams cut through the terminal moraines, where V-shaped gorges, 50 to 100 feet deep, have been cut in the till; but inasmuch as a single flood in Piney creek in the spring of 1902 cut a channel 10 to 20 feet deep, these figures must be regarded as small. In addition to the signs of freshness in the drift itself, striæ still remain on exposed surfaces of granite.

Glacial drift antedating the last.—In most of the valleys examined there are bodies of glacial drift outside of the fresh moraines referred to above, and of notably greater age. Their glacial origin is established both by the disposition of the drift in the form of well-defined lateral moraines, and by the finding of striated stones in the fresh exposures.

Their greater age is shown by the topography of the drift, by the physical condition of the material, by its topographic position, and by its patchy distribution (*Pg*, Fig. 1). The

details of the topography of this older drift, and in many cases even its larger features, are no longer glacial, but erosional. Any lakes which once existed in its surface seem to have disappeared long before the advent of the glaciers of the last epoch. This is true at any rate of that part of the drift which lies outside the newer drift, the only part now exposed. The surfaces of the *roches moutonnées* within the area of the older drift have been weathered into roughness, many of them being angular crags, while deep valleys have been cut into the drift, and 100 to 500 feet into the underlying crystalline rock. In most cases no traces of terminal moraines were found at the limit of this series of older drift deposits. From their position, such moraines were the first part of the drift to be removed. Portions of old lateral moraines are, however, preserved in some of the valleys, such as that of North Fork of Clear creek, East Fork of Big Goose creek, and at Penrose park. They have suffered considerably from stream erosion, but the even crest-line and ridge-like character are sometimes still distinct.

In general, this body of drift has been rendered notably discontinuous by erosion. The remnants are often so meager that accurate mapping of the outlines of the glaciers which made it is not practicable, though their approximate limits can usually be ascertained. In many places the remnants are restricted to hilltops.

A formation of still older (glacial ?) drift.—From the foregoing, it is clear that the Bighorn mountains were subjected to two distinct glacial régimes in the Pleistocene period. That there was a still earlier epoch of glaciation is suggested, though not proved, by the data now in hand concerning a series of deposits which antedate the older of the drift formations referred to above. Gravel, some of it containing bowlders, is widespread about the mountains. It covers the dissected plains and caps the hills which rise above them. Most of this gravel is regarded as the work of waters flowing out from the mountains and spreading on the plains. These gravels are of various ages, as their varying topographic positions show, and the oldest antedate, by some considerable period, the glacier deposits of the last

two glacial epochs. While most of the gravels seen gave no evidence of being glacial, there is on certain of the hills west of Buffalo, especially on the summit of the mountain locally known as Bald mountain[1] about six miles west southwest of Buffalo, a deposit of unconsolidated material which has something of a

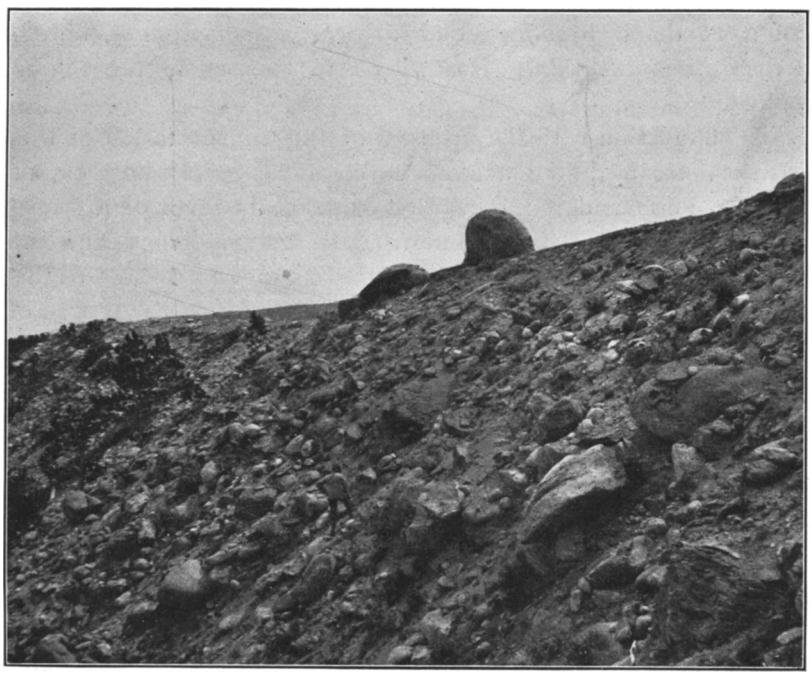


FIG. 2.— Section of the drift on the summit of Bald mountain.

glacial aspect (*P*, Fig. 1). It is made up of bowlders and stones set in a matrix of finer material (Fig. 2).

All the bowlders, so far as seen, are of igneous or metamorphic rock derived from the pre-Cambrian core of the range, the nearest part of which is more than a mile west of the locality in question. Most of them appear to have come from the higher part of the range, some 8 or 10 miles away. This material must have come across the intervening Paleozoic beds,

[1] There is another Bald mountain about 40 miles northwest of Cloud peak (see Bald Mountain quadrangle).

though no Paleozoic material was found in the deposit. This is the more remarkable since some of the gravels at lower levels in the vicinity contain a large proportion of Paleozoic material. The thickness of this body of drift was not determined, but it probably exceeds 100 feet. The plateau surface between Bald mountain and the known glacial drift has not been studied in sufficient detail to affirm that drift is absent from it, but, if present, it is certainly scattering and meager in the region visited.

In connection with the problem of the transportation of this detritus, streams and glaciers are the only agents whose claims need to be considered. Positive evidence in favor of a fluvial origin is absent, so far as known data are concerned, and the existence of numerous bowlders 15 to 25 feet in diameter militates against it, especially as the gradient between the source of the bowlders and their present position is not such as to make their reference to streams seem plausible. The summit of Bald mountain has an elevation of about 7,000 feet, and the (dissected) plateau level of the crystalline schists to the west has an elevation of about 8,500 feet some 10 miles. Bald mountain is, indeed, an isolated remnant of this plateau, the surface of which declines eastward from the base of the high part of the range which rises above it. A gradient of 150 feet or less per mile would be altogether inadequate for the transportation of such bowlders as occur on Bald mountain, by any stream which could have had its origin in this range. If river ice be assumed, the difficulty is somewhat relieved, but by no means eliminated. It is to be recognized, however, that the surface gradient may have changed since the deposit was made.

The general constitution and structure of the material are consistent with its glacial origin, though, except for the great size of some of the bowlders, perhaps not inconsistent with a torrential origin. If the deposit be glacial, the large bowlders present no difficulty, though the absence of Paleozoic material is as difficult of explanation on this hypothesis as on the other. No unequivocal striæ were found on the stones of the deposit, though somewhat careful search was made for them. Numerous

stones and bowlders were found the surfaces of which had the appearance of having been glaciated, but none which could be regarded as decisive. The failure of distinct striæ is perhaps not to be wondered at, since most of the material is so deeply weathered that but few of the bowlders retain much of the original surface. Many of the bowlders, indeed, are decayed to their centers, and many more have thick coatings of oxidized material. Furthermore, in the younger glacial drift of the present valleys, these same sorts of rock are striated but rarely.

The drift-like material on Bald mountain is separated from the Paleozoic terranes to the west by a valley 500 feet or more in depth. Farther west, a valley 1,000 feet or more in depth separates the Paleozoic terranes from the crystalline rock, whence the débris in question was derived. Whatever its origin, the drift appears to have reached its present position before these valleys were excavated. Its topographic position therefore, as well as its physical condition, points to its great age, an age which must antedate the older body of certain glacial drift (*Pg*, Fig. 1) by an interval of time greater than that which separates the two formations of known glacial drift.

Deposits which have some similarity to that on Bald mountain have some development elsewhere, but nowhere else was the suggestion of glacial drift so strong as on Bald mountain.

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